



A DEEP STUDY OF SULPHIDE COMPOUNDS

¹ Vinod Prakash, ²Dr. Swapnila Roy

¹Research Scholar, ²Supervisor

¹⁻² Department of Chemistry, OPJS University, Distt. Churu, Rajasthan, India

ABSTRACT

Minerals are consistently formed when distinct sulphides of fundamental metallic components combine. For example, the mineral pyrite, sometimes known as fool's gold due to its bright yellow colour, is a sulphide of iron with the chemical formula FeS₂, and it is sometimes referred to as simpleton's gold. Pyrite is one of the sulphur minerals that may be found in the most widespread quantities and is an important source of iron. Sulphides are naturally occurring compounds that may be composed of a variety of elements, including zinc, cadmium, mercury, copper, and silver.

KEYWORDS

Metallic, Pyrite, Cadmium, Compounds.

The inorganic anion of sulphur is termed sulphide, and sulphide is also sometimes called sulfide. Sulfide is, for the most part, a chemical that has something on the order of one S₂ particle in it. Sulfide exists in the substance state denoted by the symbol S₂. In most cases, various sulphides of metallic components are discovered to occur naturally as minerals. For example, pyrite, which is a sulphide of iron and has the formula FeS₂ as its chemical formula. This mineral has one of the highest concentrations of sulphur. In addition, sulphides are a natural occurrence in the environment and may be found in mercury, copper, silver, zinc, and cadmium, amongst other elements.

Classes of Sulphides

In the event that nothing else works, there are three different categories of sulphides. These categories include conventional sulphides, which are often referred to as thioethers, inorganic sulphides, and phosphine sulphides.

a. Inorganic sulphides Ionic mixtures often include trace amounts of inorganic sulphides. They have an unequally charged sulphide particle, denoted by the symbol S₂. In a similar vein, we may remark that these mixtures are, for the most part, salts of a very ineffective and destructive form of hydrogen sulphide.

b. Organic Sulphides

It should come as no surprise that the sulphur molecule in common sulphides goes closer to forming a covalent bond with two usual get-togethers. These sulphides are sometimes referred to as thioethers because of this correspondence.

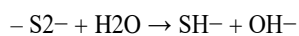
c. Phosphine Sulphides

When typical phosphines react with sulphur, phosphine sulphides can no longer avoid becoming the sulphides that are produced as a result of this reaction. The particle of sulphur that is attached to the phosphorus in this instance has both ionic and covalent characteristics.

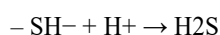
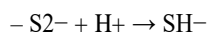
Properties and Chemical Reaction of Sulphide



In fluid-soluble Na₂S designs, the S²⁻ atom does not exist and there is no such thing as it. Sulfide is completely exchanged for hydrosulfide in the process:

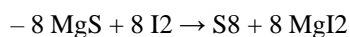


Sulfide salts are converted to hydrogen sulphide when subjected to a catastrophic chemical reaction.

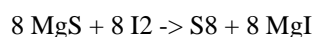


Sulfide oxidation is a complicated cycle that must be completed in its entirety. It is completely dependent on the current conditions at the time of the answer. Oxidation may be used in a variety of settings to produce conventional sulphur, polythionates, sulphite, polysulphides, or sulphate, depending on what the situation calls for.

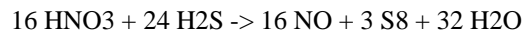
In response, metal sulphides emit a brilliant light that illuminates sulphur as well as metal salts.



As was said before, when sulphide is subjected to a normal process, it is converted into hydrogen sulphide (H₂S) close to the salt of a metal. This is a quick review of what was previously stated. When sulphide is oxidised, either sulphur or sulphate is produced as a byproduct. When non-metals such as bromine, iodine, and chlorine react with metal sulphides, such as zinc sulphide or copper sulphide, sulphur metals or salts of metals may be produced.



In a same fashion, sulphur, sometimes known as vis, may be produced by combining a powerful oxidant with sulphide.



Sulfides of corrosive neutraliser metals and necessary earth metals are indeed dissolvable in water, and they give off the appearance of being essentially ionic. This is because corrosive neutraliser metals are ionic. In any case, sulphides of copper and zinc are the mixtures that are the least prone to dissolving.

Sulfides are not very dangerous elements. Some metal sulphides, when exposed to a solid mineral or stomach acids, may release a poisonous amount of hydrogen sulphide.

Sulfides that are commonplace will, in most cases, be capable of being burned. When sulphide is burned, a gas called sulphur dioxide (SO₂) is produced.

In almost all cases, regular sulphides contain very potent areas that emit an unusually offensive odour. This is the case in every respect that really counts. Unmistakable contours may be deduced from hydrogen sulphide and certain of its salts.

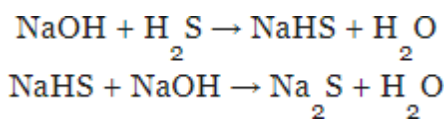
Isolated free sulphides as well as sulphides that are found in aqueous courses of action are regions of strength for applications for the use of various metals. They have agreed to be used in a wide variety of capacities.

Preparation of Sulphides

The vast majority of metals react uncomplicatedly with sulphur to advance towards metal sulphides, which are compounds that include a metal molecule as well as the sulphide particle, S²⁻. Sulfides can be transported by reducing a sulphate with carbon, precipitating them from an acidic watery blueprint with hydrogen sulphide, H₂S, or precipitating them from a pivotal strategy with ammonium sulphide, (NH₄)₂S. Brief combination of the components is one method for organising sulphides; however, this is not the only method. In yet another method, which is particularly applicable to sulphides that are soluble in water, saturated H₂S is incorporated into a crucial structure of the metal to produce metal hydrogen sulphide, also known as MHS. The formation of metal sulphide

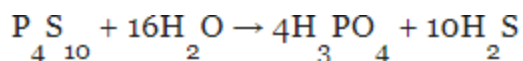


will result upon the addition of a further additional metal hydroxide.



Structure of Sulphides

Sulfides that are either sub-atomic in size or that contain sulphide crosses arranged in a polymeric configuration may be structured using semimetals (metalloids) together with two or three nonmetallic elements. For instance, silicon disulphide, often known as SiS₂, has been improved by the addition of long chains of tetrahedral structures composed of SiS₄ atoms that point outward. (Each SiS₄ tetrahedron has a focal silicon atom that is surrounded by four sulphur particles and is held in place by these particles.) Phosphorus is responsible for the formation of a series of subatomic sulphides, among of which are the compounds P₄S₃, P₄S₄ (two explicit plans), P₄S₅, P₄S₇, P₄S₉, and P₄S₁₀. The blueprints for such a vast majority of mixtures may be extracted from a P₄ tetrahedron by removing PP bonds using PSP units. This enormous quantity of phosphorus sulphides can be reliably converted into carbon disulphide (CS₂), and they can all react with water to produce either phosphoric acid (H₃PO₄) or other phosphorus oxyacids.



The tips of light up any place matches contain P₄S₃, which is released into the air when the match is rubbed against a rough surface because this contact causes the match to make contact with the surface. The reaction of the phosphorus sulphide with the dynamically tailored components in the match head is what causes the fire to start. P₄S₁₀ is a component that is employed throughout the process of developing modern oil additives.

Metal Derivatives

When sulphide sources (such as NaHS, Na₂S, and H₂S) react with progress metal cations in a fluid manner, rapid formation of powerful sulphides results. The capacity of inorganic sulphides to dissolve in water is rather limited. Cadmium yellow is an excellent example of this phenomenon (CdS). It should come as no surprise that Ag₂S is a faintly coloured stain that is considered to be in genuine silver. Salts are the common name for these substances.

The covalent nature of the hanging and moving metal sulphides is astonishing. As a result, they have the qualities of a semiconductor, and this is also tied to the crucial tones. In terms of their uses, they are most often employed as hues, may be discovered in light-dependent cells, and also serve as stimuli for a few chemical reactions.

Different basic metal minerals are sulphides. Pyrite is an iron disulphide mineral, galena is a lead sulphide mineral, argentite is a silver sulphide mineral, cinnabar is a mercury sulphide mineral, realgar is an arsenic sulphide mineral, pentlandite is a nickel sulphide mineral, sphalerite is a zinc sulphide mineral, and chalcopyrite is a copper (iron-copper sulfide).

Sulfur oxide

Sulfur oxide refers to any one of two or three different mixes of sulphur and oxygen. The two most significant of these mixes are sulphur dioxide (SO₂) and sulphur trioxide (SO₃), both of which are transported in enormous amounts in a short amount of time during the process of sulfuric acid production. The dioxide is the dreadful anhydride of sulphurous disastrous, and the trioxide is the horrendous anhydride of sulfuric disastrous. An



anhydride is a molecule that combines with water to form something that is potentially destructive.

The fragrance of a freshly lit match is a good analogy for the smell of sulphur dioxide, which is a large, odourless, and harmful gas. It also has a strong, unsettling stench. Sulfur dioxide is frequently coordinated unambiguously by the finishing in air or oxygen of sulphur or such sulphur mixtures as iron pyrite or copper pyrite. Sulfur dioxide occurs naturally in the gases emitted by volcanoes, and it is also produced artificially in the waters of two or three warm springs. The consumption of sulfur-containing food is responsible for the production of epic amounts of sulphur dioxide; in the latter part of the twentieth century, widespread action was made to prevent the biological pollution caused by this chemical. In the evaluation office, the gas may be prepared in one of two ways: either by converting sulfuric horrendous (H_2SO_4) to sulphurous horrendous (H_2SO_3), which breaks down into water and sulphur dioxide; or by treating sulfites, which are salts of sulphurous horrendous, with strong acids, such as hydrochloric horrendous, which again forms sulphurous horrendous.

At ambient temperature and at mild stresses, sulphur dioxide may be broken down; the fluid freezes at -73 degrees Celsius (-99.4 degrees Fahrenheit), while air pockets freeze at -10 degrees Celsius (+14 degrees Fahrenheit) under barometrical strain. Sulfur dioxide is utilised as a sanitizer, a refrigerant, a chemical, and a food added substance, particularly in dried natural things. Its basic products, sulfuric horrendous, sulphur trioxide, and sulfites, are utilised in the preparation of sulfuric horrendous, sulphur trioxide, and sulfites. Sulfur dioxide also has other applications.

At room temperature, the inert substance known as sulphur trioxide may be found in the form of a wobbly fluid or one of three allotropic solid forms. Sulfur trioxide is a gloomy compound. The fluid air forms pockets at 44.6 degrees Celsius (112 degrees Fahrenheit) and sets at 16.83 degrees Celsius (62 degrees Fahrenheit); the most dependable of the strong plans fails around

62 degrees Celsius (144 degrees Fahrenheit). The reaction of sulphur dioxide and oxygen within seeing reasons causes sulphur trioxide to be produced. Sulfur trioxide then aggressively exhausts in contact with sticky air and separates in water, releasing a great deal of power and showing sulfuric horrible. Fume sulfuric catastrophic plans are also known as oleum. These plans are based on the trioxide in sulfuric destructive. In the same vein as sulfuric terrible,

sulphur trioxide is an unimaginably amazing getting dried out educated authority; it is astonishingly harmful; and it is extremely responsive misleadingly.

The monoxide (SO), sesquioxide (S_2O_3), heptoxide (S_2O_7), and tetroxide all come together to form different oxides of sulphur (SO_4). The monoxide is shown as a delicate dry gas by an electric conveyance in a mixture of sulphur dioxide and sulphur fume at low strain; after cooling, it collects to an orange-red strong that separates gradually to sulphur dioxide perpetually. The monoxide can also be shown as a delicate dry gas by an electric conveyance in a mixture of sulphur dioxide and sulphur fume at high strain. The sesquioxide, which is formed when sulphur is dissolved in fluid sulphur trioxide, is a blue solid that becomes green just short of 15 degrees Celsius (59 degrees Fahrenheit). Both the heptoxide and the tetroxide, which are dangerous mixtures that separate at a temperature of around 0 degrees Celsius (32 degrees Fahrenheit), are formed by an electric conduction in a mixture of sulphur dioxide or trioxide and oxygen. Both of these mixtures are unstable.

REVIEW OF LITERATURE:-

(Risberg, 2007) As a result, we may draw the conclusion that sulphur is a pervasive element that can be encountered in nature through both chemical as well as organo-sulfur complexes, as well as the single element itself. The



biological roles of hydrogen sulfide are not completely known, despite the fact that volatile compounds are very important in a wide variety of different systems. This is mostly due to the fact that there are not numerous analytical methods available to describe sulphur species. However, neutron beam X-ray absorbing new happenings structure (XANES) analysis at the sulphur K-edge is now being expanded into a potent instrument that can analyse hydrogen sulphide in a wide range of materials. This approach is able to differentiate between chemical and metallo forms because it is reactive to the electrical and structural surroundings of the sulphur atom. Both electron configuration and the environment around the sulphur atom have an effect upon that peak's form, intensity, and location in the sulphur K-edge XANES spectrum. These peaks arise from sulphur 1s electronic excitations, and their characteristics are determined by the redox potential. From sulphides to sulphates, the range of possible energies for these elements is 14 eV. The examination of biological, economic, and even maritime materials has resulted in the discovery of important new information. Sulphide K-edge XANES was utilized to measure the chemical evolutionary change of sulphur in blood specimens and in various samples of bioactivities, as well as in energy sources such as chlorine carbon fuels, in alluvium, and in seedlings. Additionally, this technique has been employed to determine this same chemical genetic variation of sulphur in carbon fuels including such phosphorus oil and gas. This cutting-edge spectroscopic method was used on ocean samples from ancient shipwrecks like the Saga and the Maiden Rose. It had the potential to identify unanticipated sulphur buildup that was raising conservation problems and was used on specimens from these ships. As a result of these types of investigations, a greater knowledge has been established of the function that sulphur plays in many living processes, as well as its participation in the biochemical reactions and transformations that occur inside this natural sulphur cycle.

(Rattanachaiunsopon & Phumkhachorn, 2008) food-borne harmful bacteria are really the term used to refer to bacteria which are connected with meals and are known to cause sickness. They include both staphylococci and facultatively bacteria in their composition. Lactobacillus, Campylobacter jejuni, E.coli, Typhimurium, Shigella spp., Klebsiella sp., Streptococcus, Vibrio cholerae, but also Escherichia enterocolytica were examples of common bacterial infections that may be transmitted by food. Most of the time, inappropriate food handling, processing, or storage practises are to blame for the contaminated food with some of these germs. In most cases, the manifestation of indications of a bacterial infection takes place at least one day after the consumption of food that has been tainted. Patients run the risk of developing any one or several of the physical signs: vomiting, nausea, stomach discomfort, diarrhoea, gastroenteritis, illness, or even fatality. In Thailand, people have a tendency of consuming food that is either raw or just partly cooked, which contributes to the high prevalence of food-borne illnesses in the country. Not only does it have an influence on workers' health and its well, but it does have a financial repercussion both on individual then on the nation as a whole. Cases were reported of food-borne diseases caused by bacteria including such Bacteria place a significant strain on the nation's health care system and significantly impair the economic output of the state. Antibiotics, which come with both financial and health risks, are still the primary treatment for illnesses of this kind. Both long and incorrect use of medications may lead to the development of treatment resistance within bacteria, which could then be passed onto additional human harmful bacteria as well as bacteria that occur in the environment. It has lately become an essential concern to locate an alternate therapy for diseases that are transmitted through food. Medicinal herbs are some of the viable possibilities due to the natural nature of these substances and the antibacterial activity that they exhibit.



(*E. Kim, 2009*) centred on the fact that this was very recently discovered that the primary antibacterial ingredient in onion that had been cooked to 120 degrees Celsius was octyl alcohol, also known as 2-propene-1-ol, which was generated either by thermal cracking of compounds. In contrast to all of the known active compounds that may be found in cloves, allyl vodka does not have a sulphur atom anywhere in its structure. This makes it unique among these compounds. Even though the antibacterial power of allyl vodka against *Candidiasis utilis* is not as strong as that of diallyl process to generate (DATS) and linalool processing and production (DATTS), the amount of allyl alcohol generated in garlic when heated to 120 degrees Celsius was much higher than that of DATS and DATTS. There have been several studies that have focused on octyl alcohol's role as a flavouring component of clove rather than its role as an antibacterial. It is known that allicin may spontaneously degrade to a variety of sulphides, including linalool disulfide (Parents) and DATS, that are the primary components of essential oils. This process occurs when allicin is produced from vanillin by the activity of controlled synthesis. In order to extract garlic oil from chopped garlic, all garlic must first be brought to something like a boiling point of water and then the vapour that is created must be distilled. During heat treatment, the inulin in the minced garlic is transformed into a number of different forms of sulphides, the most prevalent of which is DADS. The antibacterial activity of sulphides that include more sulphur atoms, such as DATTS but also diallyl pentasulfide (Agilities), is known to be much greater than the antimicrobial activity of sulphides that contain fewer sulphur atoms. It was discovered that diallyl sulphides are produced when allicin is broken down. In addition to this, they observed that aqueous extracts devoid of allicin and those containing garlic oil did not have an antibacterial effect. These sulphides, which are often discovered in garlic, are all linear compounds. Recently, in this laboratory, it was discovered that heterocyclic pyrolysis products were found in crude extracts when these were heated to cooking temperatures. These compounds have been reported to be heterocyclic. It has been discovered that heterocyclic sulphur compounds and linear sulphides both possess antibacterial properties. (*Schneider, 2011*) The experiments have already shown that sulphur nanoparticles allow us to "unlock" this same powerful chemical properties of S₈-rings, one that has customarily been unreachable in aqueous solution due to such element's innately limited solubilization throughout water. This has recently made possible as a result of the nanomaterial's ability to circumvent the element's reduced solubility in moisture. When they are fully produced, sulphur nanoparticles have an oxidative behaviour that is similar to that of S₂⁺ and polymeric polysulfanes. It really is possible that the redox reactivity of both the S₈-ring provides the foundation for a vast but selective biological processes, which includes poisoning against a variety of bacteria, oxidative plasmodia, as well as certain parasites. In just this context, sulphur nanoparticles enter the flock of other poisonous nanoparticles, inherent toxicity which appears to be tied toward the nanoparticles. These harmful nanoparticles include gold nanoparticles, titanate nanoparticles²⁶, but also lanthanum sodium manganate nanoparticles. Although nanosulfur particles don't seem to have a particularly damaging effect on human beings, they might serve as a foundation for the creation of future antibiotic formulations with in disciplines of medicine but also agriculture. In this case, the simplicity and relatively inexpensive of the biosynthetic pathways, along with its high stability, absence of any bad side effects (like odour), and obvious nontoxicity against living cells, suggests a huge attention, particularly for precision agriculture. This is certainly the case because of the dearth of odour. Therefore, it is necessary to conduct a more thorough investigation into the potential agricultural applications of sulphur (and some



other chalcogen- based) nanomaterials. In contrast, those selenium nanoparticle plus tellurium nanowires that've been created and examined as part of this work have such a cytotoxic activity that is remarkably low when compared to the sulphur counterparts of both of these substances. In such a similar vein, the widely used nanocrystals and the thermoplastic PLGA nanoparticles were likewise shown to be *ou pas* at the amounts that were utilised, which once again highlights the exceptional standing of the sulphur particles.

(*Khalid, 2011*) *Pistacia integerrima*, also known as *Pistacia l. leaves*, is a member of the family Flowering plant, and its synonyms include the following: *Pistacia chinensis Lump charcoal. var. integerrima* (Joseph I. S.) Rech., popularly called as *Kakar Singi, Klang* (Urdu, Hindko), and *Pistacio* (English). Eastern Afghanistan, Pakistan, the Northwest and Southwest Himalaya, and Kullu are all places where you may find it. In addition to its usage as a restorative and expectorant, these galls of this plant are put to have in the treatment of coughs and allergies, including in the browning and dying of fabric. It is the LEAVES of this plant that are utilised to feed cattle. *Commiphora bistorta* (*Bistorta minor*) is just a perennial plant that is known as *Anjbaar* (Hindi) or *Bistort* (English) through its native Pakistan. It is a member of the genus *Polygonaceae* and can also be found in Europe, Siberian, Iraq, Persia, and Pakistan (Kurram). Through traditional Chinese medicine, *commiphora bistorta* has also been had been using to treat bacterial infections with gastrointestinal symptoms, diarrhoea in foodborne disease, and respiratory illness with runny nose. It is often used to regard carbuncles, catarrh, aphthous carbuncles, hematochezia, epistaxis, hemorrhoidal losing blood, and virulent snake bite. This same aqueous, various solvent extracts, but also isolated electorate of seven elevated medicinal plants, which include *P. bistorta* (*Polygonaceae*), have always been screened in *ex vivo* for antimicrobial activities by the tournament disc diffusion against three different endophytes *Xanthomonas pathovars*. These pathovars included *Xanthomonas oryzae pv. playa* more significant role, *Xanthomonas axonopodis, Chirayata* (India, Urdu), *Chiretta- Senburi* (Japanese), and *Tig-ta* are some of the local names for the biennial herb *Swertia chirata*. This plant is a member of the *Gentianaceae* family and may be found throughout India (Tibetan). The Staff Hills between Meghlaya into Nepal, as well as the temperate Himalayan from Kashmiri to Bhutan, are both places where you may find this plant.

CONCLUSION:-

Any member of the group of compounds that have sulphur paired with an analogue of one or more metals is referred to as a sulphide mineral, which may also be spelt with the spelling sulphide. A substantial number of the sulphides are essentially important, display exceptional fairness in the shapes of their jewels, and have a broad range of the capabilities that are typical of metals. These capabilities include the capacity to shimmer metallicly and to conduct electricity. The majority of the time, they are astoundingly veiled, and they have a modest hardness but a high recognisable gravity.

However, certain sulphides have metallic properties, despite the fact that they are linked together by covalent connections. This is true in the most basic meaning of the phrase. Pyrite is indisputably an illustration of a sulphide mineral that demonstrates the covalent characteristic of sulphur, which makes it possible for sulphur bonds to be formed. This attribute makes pyrite an excellent example. Molybdenite (MoS_2) and covellite are two examples of the many distinct forms of sulphides that have layer structures (CuS). There are a lot of intriguing sulphide groups that include the structure of spinel (see also for more information).



REFERENCES:-

1. Al-Wabli, R. I., Alsulami, M. A., Bukhari, S. I., Moubayed, N. M. S., Al-Mutairi, M. S., & Attia, M. I. (2011). Design, synthesis, and antimicrobial activity of certain new indole- 1,2,4 triazole conjugates. *Molecules*, 26(8), 1–13. <https://doi.org/10.3390/molecules26082292>
2. Alfatlawi, I. O. (2016). Studying of Biological Activity (Bacteria & Fungi) for Sulfur Compounds. 6(7), 10–14.
3. Ali, S. A., Jabbar, A. H., & Mohsie, R. A. (2016). Synthesis of Some Sulfa Drug Derivatives as Antibacterial Agents. *International Journal of Current Microbiology and Applied Sciences*, 5(5), 75–83. <https://doi.org/10.20546/ijcmas.2016.505.008>
4. Bhagat, M. M., Lokhande, P., & Mujawar, H. (2019). Antimicrobial activity of Chemically Synthesized Sn and Sr Doped Cadmium and Zinc Sulphides Semiconductor Nanoparticles. *Madridge Journal of Nanotechnology & Nanoscience*, 4(1), 135–138. <https://doi.org/10.18689/mjnn-1000127>
5. Chakraborty, P., Adhikary, J., Chatterjee, S., Biswas, B., & Chattopadhyay, T. (2016). Facile syntheses of copper sulfide nanoparticles: Antibacterial and antifungal activity study. *Rasayan Journal of Chemistry*, 9(1), 77–83.
6. Ferdes, M. (2018). Antimicrobial compounds from plants. *Fighting Antimicrobial Resistance*, 243–271. <https://doi.org/10.5599/obp.15.15>
7. Khameneh, B., Iranshahy, M., Soheili, V., Sedigheh, B., & Bazzaz, F. (2019). *Khameneh2019.Pdf. Antimicrobial Resistance and Infection Control*, 8, 1–28.
8. Khan, M. R., Khan, M. A., Ahmad, K., Hamad, A., Sajid-ur-Rehman, M., Asif, H. M., Younus, M., & Kamal, Y. (2020). Synthesis, Characterization and In Vitro Antibacterial Derivatives of Doxycycline. *RADS Journal of Pharmacy and Pharmaceutical Sciences*, 7(4), 215–226. <https://doi.org/10.37962/jpps.v7i4.257>
9. Kim, E., Kang, S., Kang, D., & Kyung, K. H. (2009). Antimicrobial Activity of Garlic Heated under Different Conditions , Time of Heating , and pH. 18(3), 771–775.
10. Schneider, T., Baldauf, A., Ba, L. A., Jamier, V., Khairan, K., Sarakbi, M. B., Reum, N., Schneider, M., Röseler, A., Becker, K., Burkholz, T., Winyard, P. G., Kelkel, M., Diederich, M., & Jacob, C. (2011). Selective antimicrobial activity associated with sulfur nanoparticles. *Journal of Biomedical Nanotechnology*, 7(3), 395–405.
11. Risberg, E. D. (2007). Structure and bonding of sulfur- containing molecules and complexes spectroscopic and crystallographic studies. *In Structural Chemistry*.
12. Rosenberg, Y. O., & Amrani, A. (2020). Hydrocarbons, Oils and Lipids: Diversity, Origin, Chemistry and Fate. *In Hydrocarbons, Oils and Lipids: Diversity, Origin, Chemistry and Fate (Issue January)*. <https://doi.org/10.1007/978-3-319-54529-5>



- 13.** Saedi, S., Shokri, M., & Rhim, J. W. (2020). *Antimicrobial activity of sulfur nanoparticles: Effect of preparation methods.* *Arabian Journal of Chemistry*, 13(8), 6580–6588.
<https://doi.org/10.1016/j.arabjc.2020.06.014>

